

Indicator: Hypoxia in the Northern Gulf of Mexico and in Long Island Sound (238R)

Nutrient pollution is one of the most pervasive and troubling pollution problems facing U.S. coastal waters (U.S. Commission on Ocean Policy, 2004). More than half of the nation's estuaries experience low levels of dissolved oxygen (hypoxia) and other symptoms of eutrophication (Bricker et al. 1999). The Gulf of Mexico and Long Island Sound are prime examples of coastal and estuarine areas experiencing eutrophic conditions. While hypoxia can occur naturally and has existed throughout geologic time, its occurrence in shallow coastal and estuarine areas appears to be increasing and is most likely accelerated by human activities (Vitousek et al. 1997; Jickells 1998). As a result, coastal ecosystems suffer a number of environmental problems that can, at times, be attributed to the introduction of excess nutrients from upstream watersheds (NRC, 2000). Tracking dissolved oxygen conditions provides an indicator of whether nutrients are a concern, whether actions to control nutrients are having the desired effect, and of the natural variability in the condition of the waterbodies.

Concentrations of dissolved oxygen above 5 mg/L are supportive of marine life. As oxygen levels fall, the effects on aquatic life become more severe. At about 3 mg/L, bottom living fishes start to leave the area, and the growth of sensitive species such as crab larvae is reduced. At 2.5 mg/L, the larvae of even less sensitive species of crustaceans start to die, and the growth of crab species is more severely limited. At levels less than 2 mg/L, some juvenile fish and crustaceans that cannot leave the area start to die. At levels less than 1 mg/L, fish totally avoid the area or begin to die in large numbers (Howell and Simpson, 1994, U.S. Environmental Protection Agency, 2000).

This indicator tracks trends in hypoxia in the Gulf of Mexico and in Long Island Sound.

The Gulf of Mexico hypoxic zone on the Texas-Louisiana Shelf is the largest zone of coastal hypoxia in the Western Hemisphere (CAST, 1999). It exhibits seasonally low oxygen levels as a result of complicated interactions involving excessive nutrients carried to the Gulf by the Mississippi and Atchafalaya Rivers; physical changes in the basin, such as channelization, construction of dams and levees, and loss of natural wetlands and vegetation along the banks and wetland conversion throughout the basin; and the stratification in the waters of the northern Gulf caused by the interaction of fresh river water and the saltwater of the Gulf (CENR, 2000). Increased nitrogen and phosphorus inputs from human activities throughout the basin cause the production of an overabundance of algae, which die and fall to the sea floor, where they consume oxygen. Fresh water from the rivers entering the Gulf of Mexico forms a fresh water layer above the saltier Gulf of Mexico waters and prevents re-oxygenation of oxygen depleted water along the bottom. The Gulf of Mexico indicator is based on data collected at least annually, although recently there have been as many as four surveys per year. The number of locations varies from 60-90 depending on the length of the cruise, the size of the hypoxic zone, logistical constraints, and the density of station locations. The surveys usually occur in mid-July to late-July.

In Long Island Sound, seasonally low levels of oxygen usually occur in bottom waters from mid-July through September, and are more severe in the western portions of the Sound, where the nitrogen load is higher and stratification is stronger, reducing mixing and reaeration processes (Welsh et al. 1991). While nitrogen fuels the growth of microscopic plants that leads to low levels of oxygen in the Sound, temperature, wind patterns, rainfall, and salinity, also contribute. The low levels of oxygen impair the feeding, growth, and reproduction of aquatic life in the Sound. The Long Island Sound indicator is based on bi-weekly surveys conducted at 36 sites from mid-June through September. The indicator includes both extent and duration of the hypoxic period.

What the Data Show

The size of the hypoxic zone in the Gulf of Mexico has varied considerably since 1985 (Figure 238R -1). Between 1993 and 1999 the zone of midsummer bottom-water hypoxia area (<2 mg/L) in the Northern Gulf of Mexico was estimated to be larger than 4,000 square miles. In 1999, it increased to 8,000 square miles, but in 2000, the zone was reduced to only 1,700 square miles. In the latest year of sampling, 2004, the hypoxic zone measured over 5,800 square miles (Figure 238R-2). The five year running average for the years 1996 – 2000 was 5,454 square miles.

The area and duration of moderate hypoxic (less than 3 mg/l) in Long Island Sound also has varied considerably since 1987, and in most years, the lowest dissolved oxygen levels are found in the western end of the Sound (Figure 238R-3). Since 1987, the largest area of DO less than 3 mg/l was 393 square miles and occurred in 1994. The smallest area, 30 mi², occurred in 1997. The shortest duration of moderate hypoxia was 34 days in 1996 and the longest duration, 82 days, in 1989. While there are year-to-year variations in water quality conditions, there has been an overall trend toward less severe hypoxia since 1987, as indicated by the area and duration of DO < 3 mg/l. In 2004, the latest year for which data are available, the maximum area and duration of DO 3 mg/l in Long Island Sound was 202 square miles and 60 days, respectively (Figure 238R-4). The 18 year averages are 210 mi² and 57 days.

Indicator Limitations

Gulf of Mexico

- Anoxic periods (no oxygen at all) occurring at times other than the mid-summer surveys are not captured in the indicator.
- The extent of hypoxia is generated during a single midsummer sampling cruise, so duration cannot be estimated.
- Surveys usually end offshore the Louisiana-Texas State line; in years when hypoxia extends onto the upper Texas coast, the areal extent of hypoxia is underestimated.

Long Island Sound

- Anoxic period that may occur between the two week surveys are not captured in the indicator. two weeks during the critical summer period.
- Samples are taken in the daytime, approximately one meter off the bottom. Lower oxygen conditions at night or near the sediment-water interface are not captured by the indicator.

Data Sources

Committee on Environment and Natural Resources (CENR). 2000. Integrated Assessment of Hypoxia in the Northern Gulf of Mexico. National Science and Technology Council Committee on Environment and Natural Resources, Washington, DC.
http://www.nos.noaa.gov/Products/pubs_hypox.html Council for Agricultural Science and Technology (CAST). 1999. Gulf of Mexico Hypoxia: Land and Sea Interactions. Task Force Report No. 134.

National Coastal Condition Report (NCCR). 2001. EPA-620/R-01/005. Office of Research and Development/Office of Water, Washington, DC.

Rabalais, N.N., Louisiana Universities Marine Consortium, 8124 Hwy. 56, Chauvin, LA 70344.

Rabalais, N.N. and R.E. Turner (eds.). 2001. Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C., 454 p.

Rabalais, N.N., R.E. Turner and D. Scavia. 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River. *BioScience* 52: 129-142.

Scavia, D., N.N. Rabalais, R.E. Turner, D. Justić, and W.J. Wiseman, Jr. 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. *Limnology & Oceanography* 48: 951-956.

Turner, R.E., N.N. Rabalais, E.M. Swenson, M. Kasprzak and T. Romaine. 2005 (online www.sciencedirect.com Aug 2004). Summer hypoxia in the northern Gulf of Mexico and its prediction from 1978 to 1995. *Marine Environmental Research* 59: 65-77.

Connecticut Department of Environmental Protection.

<http://dep.state.ct.us/wtr/lis/monitoring/monsum.htm>

http://dep.state.ct.us/wtr/lis/monitoring/lis_page.htm

References

Howell, P. and Simpson, D. Abundance of Marine Resources in Relation to Dissolved Oxygen in Long Island Sound. *Estuaries*. 17:394-402. 1994.

U.S. Commission on Ocean Policy. An Ocean Blueprint for the 21st Century. Final Report. Washington, D.C. ISBN#0-9759462-0-X. 2004

U.S. Environmental Protection Agency. Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras. EPA 822-R-00-12. Office of Water/Office of Science and Technology and Office of Research and Development/National Health and Environmental Effects Research Laboratory. November 2000.

Welsh, B.L. and F. C. Eller. Mechanisms Controlling Summertime Oxygen Depletion in Western Long Island Sound. *Estuaries*. 14:265-278. 1991.

Bricker, S.B., et al. 1999. *National eutrophication assessment: Effects of nutrient enrichment in the nation's estuaries*. Silver Spring, MD: NOAA National Ocean Service. 71 pp.

Vitousek, Peter M. et al. 1997. Human alteration of the global nitrogen cycle: Sources and consequences, ecological applications. *Ecological Applications* 7(3):737-50.

Jichells, T.D. 1998. Nutrient biogeochemistry of the coastal zone. *Science* 281:217-21.

National Research Council (NRC). 2000. Clean Coastal Waters: understanding and reducing the effects of nutrient pollution. National Academy Press, Washington, DC, 405 pp.

Graphics

Figure 238R-1: Estimated Size of Bottom-Water Hypoxia in Mid-Summer

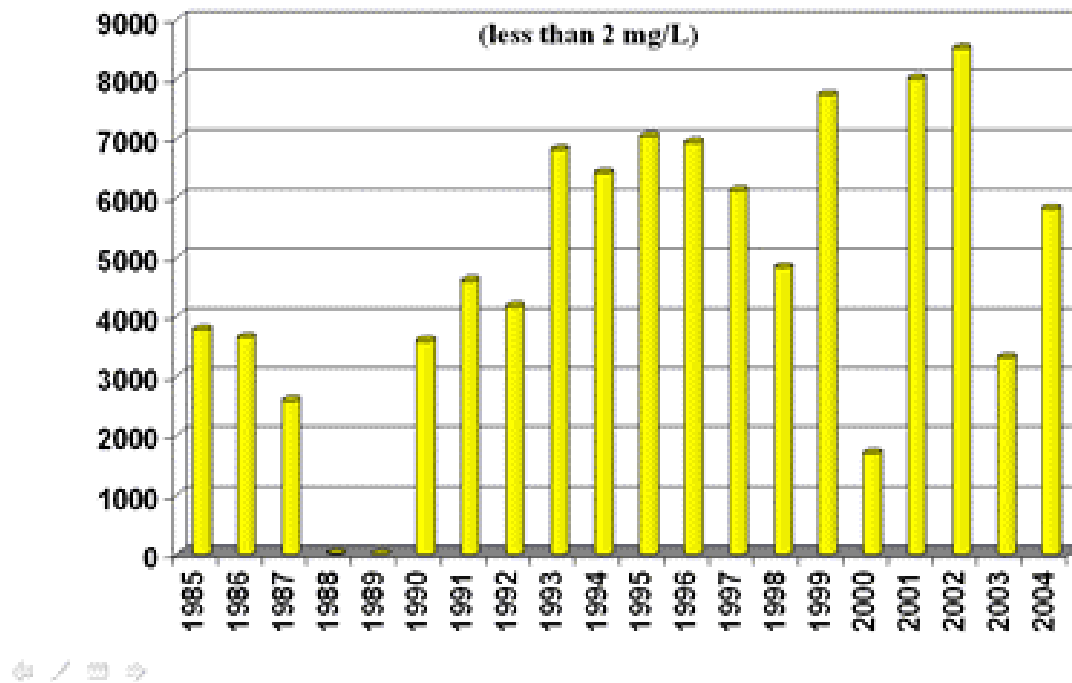


Figure 238R-2: July 21-25, 2004 - Area of Bottom Hypoxia

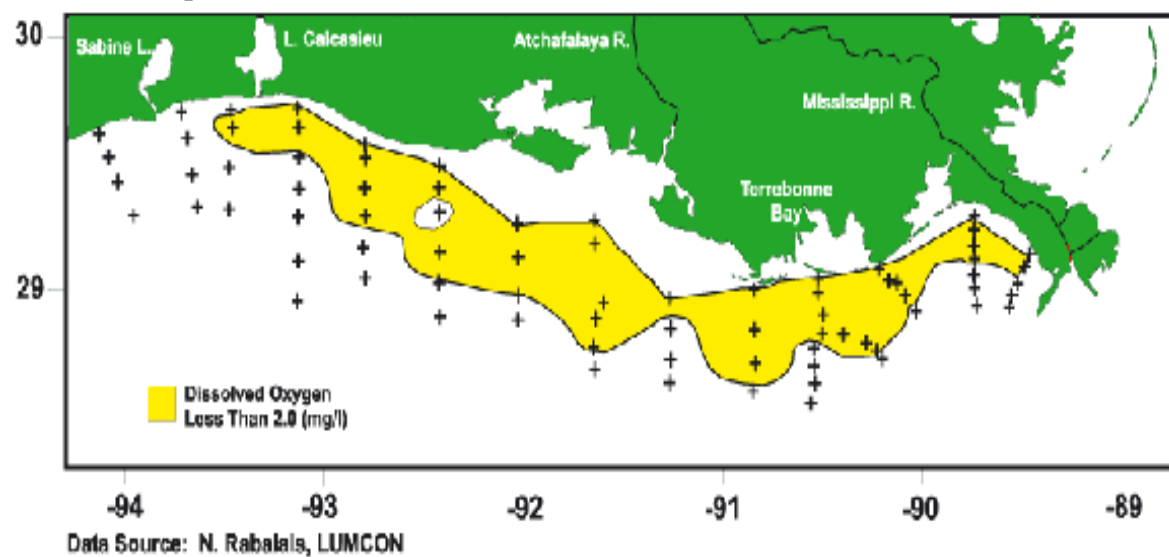


Figure 238R-3: Maximum Area and Duration of Hypoxia in Long Island Sound
(less than 3.0 mg/l)

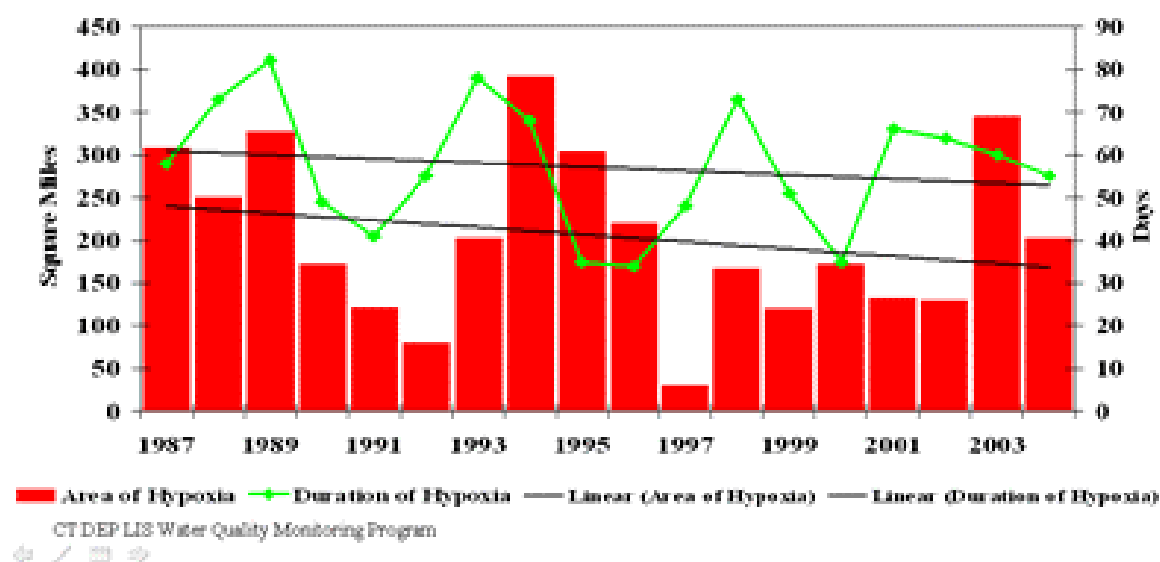
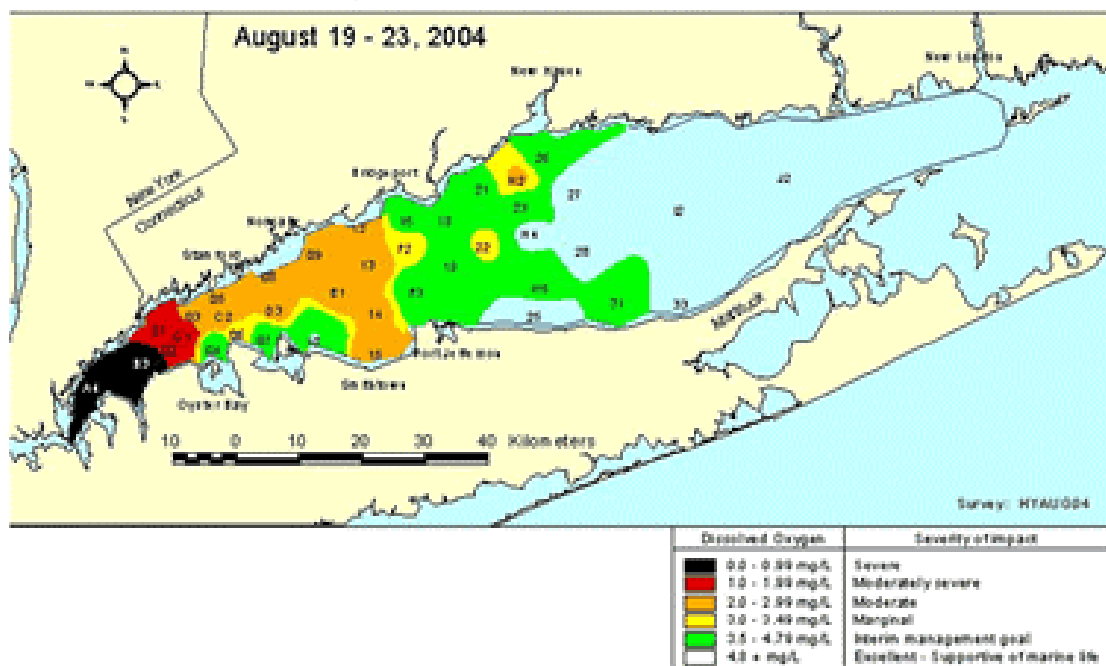


Figure 238R-4:
Dissolved Oxygen in Long Island Sound Bottom Waters



R.O.E. Indicator QA/QC

Data Set Name: EXTENT OF HYPOXIA IN GULF OF MEXICO AND LONG ISLAND SOUND

Indicator Number: 238R (89157)

Data Set Source: Hypoxia Studies of Rabalais et al.

Data Collection Date: mid to late July.

Data Collection Frequency: Yearly, 1985 to present (not 1988)

Data Set Description: The Areal Extent of Hypoxia in the Gulf of Mexico and Long Island Sound

Primary ROE Question: What are the trends in extent and condition of coastal waters

Question/Response

T1Q1 Are the physical, chemical, or biological measurements upon which this indicator is based widely accepted as scientifically and technically valid?

Yes, we follow standard procedures as outlined in our proposals to NOAA, peer-reviewed publications, and reports sent to NOAA. Rabalais, N.N., Louisiana Universities Marine Consortium, 8124 Hwy. 56, Chauvin, LA 70344. Rabalais, N.N. and R.E. Turner (eds.). 2001. Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C., 454 p. Rabalais, N.N., R.E. Turner and D. Scavia. 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River. *BioScience* 52: 129-142. Scavia, D., N.N. Rabalais, R.E. Turner, D. Justi, and W.J. Wiseman, Jr. 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. *Limnology & Oceanography* 48: 951-956. Turner, R.E., N.N. Rabalais, E.M. Swenson, M. Kasprzak and T. Romaine. 2005 (online www.sciencedirect.com Aug 2004). Summer hypoxia in the northern Gulf of Mexico and its prediction from 1978 to 1995. *Marine Environmental Research* 59: 65-77.

T1Q2 Is the sampling design and/or monitoring plan used to collect the data over time and space based on sound scientific principles?

Yes, we conduct the survey in a consistent manner from year to year so that the data are comparable. The data collection procedures are documented in several peer-reviewed publications. Rabalais, N.N., Louisiana Universities Marine Consortium, 8124 Hwy. 56, Chauvin, LA 70344. Rabalais, N.N. and R.E. Turner (eds.). 2001. Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C., 454 p. Rabalais, N.N., R.E. Turner and D. Scavia. 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River. *BioScience* 52: 129-142. Scavia, D., N.N. Rabalais, R.E. Turner, D. Justi, and W.J. Wiseman, Jr. 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. *Limnology & Oceanography* 48: 951-956. Turner, R.E., N.N. Rabalais, E.M. Swenson, M. Kasprzak and T. Romaine. 2005 (online www.sciencedirect.com Aug 2004). Summer hypoxia in the northern Gulf of Mexico and its prediction from 1978 to 1995. *Marine Environmental Research* 59: 65-77.

T1Q3 Is the conceptual model used to transform these measurements into an indicator widely accepted as a scientifically sound representation of the phenomenon it indicates?

THE DATA PRESENTED IN THE HISTOGRAM ARE DATA POINTS OF ESTIMATED SIZE DEVELOPED FROM THE BOTTOM-WATER DISSOLVED OXYGEN DATA OVER A 5-DAY PERIOD IN MID-SUMMER.

T2Q1 To what extent is the indicator sampling design and monitoring plan appropriate for answering the relevant question in the ROE?

The sampling design and timing of sampling is appropriate for determining the expected maximal extent of summertime bottom-water hypoxia. The number of locations varies from 60-90 depending on the length of the cruise, the size of the hypoxic zone, logistical constraints, and the density of data points (station locations). The beginning and ending dates are found on each graph, and stored with the data at NOAA NODC. They usually occur in mid-July to late-July, but not always.

T2Q2 To what extent does the sampling design represent sensitive populations or ecosystems?

The sample design represents the area most likely to have hypoxic bottom-waters in mid-summer. The mapping exercise maximized the ability to obtain values below 2 mg/l and above 2 mg/l on each transect so that closed contours can be drawn from the data points.

T2Q3 Are there established reference points, thresholds or ranges of values for this indicator that unambiguously reflect the state of the environment?

The nominal definition of hypoxia for the study area is 2 mg/l, based on observational data from trawl surveys that indicate demersal catch is minimal or non-existent when the oxygen is below 2 mg/l. The definition of hypoxia is consistent across the spatial and temporal extent of the data set. The data can also be expressed in percent saturation of dissolved oxygen, which takes into account temperature, salinity, and density. The map contours, however, are drawn only on values in mg/l.

T3Q1 What documentation clearly and completely describes the underlying sampling and analytical procedures used?

The metadata are stored at <http://www.cast-net.org/metadata/>

T3Q2 Is the complete data set accessible, including metadata, data-dictionaries and embedded definitions or are there confidentiality issues that may limit accessibility to the complete data set?

The data are submitted to NOAA NODC after appropriate QA/QC and completion of metadata. Backup copies are maintained by the Hypoxia Studies group at LUMCON, Nancy Rabalais or Adam Sapp at nrabalais@lumcon.edu or asapp@lumcon.edu, 985-851-2800 for switchboard.

T3Q3 Are the descriptions of the study or survey design clear, complete and sufficient to enable the study or survey to be reproduced?

Yes <http://www.cast-net.org/metadata/>

T3Q4 To what extent are the procedures for quality assurance and quality control of the data documented and accessible?

No, the routine for QA/QC differs by variable of measurement. There is no software. The protocols are included in the metadata. The areal estimate is just that an estimate. QA/QC is performed by the Hypoxia Studies group at LUMCON, Nancy Rabalais or Adam Sapp at nrabalais@lumcon.edu or asapp@lumcon.edu, 985-851-2800 for switchboard.

T4Q1 Have appropriate statistical methods been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)?

Yes. Scavia, D., N. N. Rabalais, R. E. Turner, D. Justic, and W. J. Wiseman, Jr. 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. *Limnology & Oceanography* 48: 951-956. Turner, R. E., N. N. Rabalais, E. M. Swenson, M. Kasprzak and T. Romaine. 2005 (online www.sciencedirect.com Aug 2004). Summer hypoxia in the northern Gulf of Mexico and its prediction from 1978 to 1995. *Marine Environmental Research* 59: 65-77. And 2 as yet to be published models.

T4Q2 Are uncertainty measurements or estimates available for the indicator and/or the underlying data set?

No. The indicator is an estimated size.

T4Q3 Do the uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

No. Sources of error are not being able to complete the survey, not being able to reach the shallowest depths of hypoxia because of the draft of the vessel, inexactness of the hand contouring versus digitized contours. The sampling and monitoring design is sound for generating an estimate of the size of hypoxia during a 5-6 day period in mid summer.

T4Q4 Are there limitations, or gaps in the data that may mislead a user about fundamental trends in the indicator over space or time period for which data are available?

Anoxic periods (no oxygen at all) occurring at times other than the mid-summer surveys are not captured in the indicator. The extent of hypoxia is generated during a single midsummer sampling cruise, so duration cannot be estimated. Surveys usually end offshore the Louisiana-Texas State line; in years when hypoxia extends onto the upper Texas coast, the areal extent of hypoxia is underestimated. There are no gaps in the data that serve to generate the bottom-water hypoxia contours. To properly interpret the size data from one year to the next, the user needs to know basic biological processes, the physical oceanography of the northern Gulf of Mexico, the seasonal dynamics of the biological/physical interactions that lead to the formation and maintenance of hypoxia, the condition of river discharge and nutrient flux for the period (up to 6 months) prior to the mapping cruise, the weather conditions prior to the cruise and during the cruise, the occurrence, timing, and severity of any tropical storm activity prior to the cruise, the wind speed, wind direction, and wave state, the current conditions (ADCP data gathered en route).

R.O.E. Indicator QA/QC

Data Set Name: EXTENT OF HYPOXIA IN GULF OF MEXICO AND LONG ISLAND SOUND - PART 2 OF 2

Indicator Number: 238R (114848)

Data Set Source: LIS Study Monitoring Program conducted by the Connecticut Department of Environmental Protection

Data Collection Date: regular: 1987-present

Data Collection Frequency: monthly October-May, biweekly June-September

Data Set Description: The Areal Extent of Hypoxia in the Gulf of Mexico and Long Island Sound - Long Island Sound QA, See part 1 for Indicator Text and graphics.

Primary ROE Question: What are the trends in extent and condition of coastal waters

Question/Response

T1Q1 Are the physical, chemical, or biological measurements upon which this indicator is based widely accepted as scientifically and technically valid?

Yes, standard procedures are used and are documented in the program's Environmental Research Institute Standard Operating Procedures For Long Island Sound Study(2001) and revised Quality Assurance Project Plan (April 2002. Copies are available upon request. The method used to measure dissolved oxygen is Winkler titration. Precision is within 0.5 mg/l.

T1Q2 Is the sampling design and/or monitoring plan used to collect the data over time and space based on sound scientific principles?

Yes. The sampling design is described in the report Long Island Sound Ambient Monitoring Program: Hypoxia Monitoring Survey 1991-1998 Data Review (CTDEP, 2000). The sampling design has also been used for the EPA National Coastal Assessment monitoring program, through a cooperative agreement between EPA and CTDEP.
http://dep.state.ct.us/wtr/lis/monitoring/lis_page.htm

T1Q3 Is the conceptual model used to transform these measurements into an indicator widely accepted as a scientifically sound representation of the phenomenon it indicates?

There is no conceptual model. The data presented in the histogram are estimates of the area and duration of hypoxia determined from the spatial and temporal sampling effort.

T2Q1 To what extent is the indicator sampling design and monitoring plan appropriate for answering the relevant question in the ROE?

The indicator directly responds to the question, what is the status and trends in the severity of hypoxia in LIS? Severity is considered by both the maximum hypoxic area and duration of time it persists. While a more frequent and dense sampling design would improve the precision of the estimates, the benefits would not be worth the added cost. The indicator is directly in response to an issue of national concern. The US Commission on Ocean Policy identified impairment of coastal waters due to nutrient enrichment as a national problem. The Commission also recommended that EPA set measurable pollution reduction targets for coastal waters and take steps to reduce nutrient pollution from point and nonpoint sources to nutrient-impaired waterbodies. This indicator directly measures

the status and trends in the quality of a nutrient-impaired waterbody, Long Island Sound. Furthermore, EPA and the states of NY and CT have set nitrogen reduction targets for LIS to address the impairment.

T2Q2 To what extent does the sampling design represent sensitive populations or ecosystems?

The sampling design is meant to characterize conditions throughout LIS and not target subareas. However, sampling frequency is increased from monthly to biweekly during the summer to capture water quality conditions during this critical period when hypoxia occurs.

T2Q3 Are there established reference points, thresholds or ranges of values for this indicator that unambiguously reflect the state of the environment?

There is no universal definition of hypoxia. There are effects gradients over a range of concentrations that will vary with the resources being affected. The LIS indicator uses concentrations below 3.0 mg/l of dissolved oxygen as a working definition of hypoxia. This is clearly a concentration of concern based on EPA's marine DO criteria and reflects impairments to water quality standards.

T3Q1 What documentation clearly and completely describes the underlying sampling and analytical procedures used?

Standard procedures are used and are documented in the Environmental Research Institute Standard Operating Procedures For Long Island Sound Study(2001) and revised Quality Assurance Project Plan (CTDEP, April 2002). Copies are available upon request. EPA has reviewed and approved the QAPP for the program.

T3Q2 Is the complete data set accessible, including metadata, data-dictionaries and embedded definitions or are there confidentiality issues that may limit accessibility to the complete data set?

The complete data set is available: Matthew Lyman CTDEP 860-424-3158
matthew.lyman@po.state.ct.us

T3Q3 Are the descriptions of the study or survey design clear, complete and sufficient to enable the study or survey to be reproduced?

Yes. Complete descriptions are documented in the project QAPP and related reports.

T3Q4 To what extent are the procedures for quality assurance and quality control of the data documented and accessible?

The QAPP has been developed by CTDEP and approved by EPA. The QAPP documents all QA/QC procedures.

T4Q1 Have appropriate statistical methods been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)?

Yes, the data are presented only for the time and area collected. Simple contour plots are prepared to graphically show the areal distribution of dissolved oxygen in bottom waters during the summer. The maximum area and maximum duration (in days) less than 3 mg/l each year are presented from 1987-1994.

T4Q2 Are uncertainty measurements or estimates available for the indicator and/or the underlying data set?

No. The indicators are estimated size and duration measures.

T4Q3 Do the uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

No. Sources of error are not being able to complete a survey, not being able to reach shallow areas due to the draft of the boat, and the inexactness of contour plotting.

T4Q4 Are there limitations, or gaps in the data that may mislead a user about fundamental trends in the indicator over space or time period for which data are available?

There is no limitation that could lead to a fundamental error. Anoxic period that may occur between the two week surveys are not captured in the indicator. Two weeks during the critical summer period. Samples are taken in the daytime, approximately one meter off the bottom. Lower oxygen conditions at night or near the sediment-water interface are not captured by the indicator. Additional temporal and spatial sampling would provide greater resolution of conditions, but would be unlikely to fundamentally change the conclusions on the indicator.